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In re Patent Application of: **SMITH**	)
Serial No. **09/441,709**	)
Filing Date: **NOVEMBER 16, 1999**	)
For: **DEFECT CORRECTION IN ELECTRONIC IMAGING SYSTEM**	)

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Transmitted herewith is a certified copy of the priority United Kingdom Application No. 9825086.3.

Respectfully submitted,

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1. Your reference — P22159/ALO/JCO

2. Patent application number *(The Patent Office will fill in this part)* — **9825086.3** 17 NOV 1998

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if you know it)* — 755177 3001

If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

4. Title of the invention — "Defect Correction in Electronic Imaging Systems"

5. Name of your agent *(if you have one)* — Murgitroyd & Company

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

373 Scotland Street
GLASGOW
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Patents ADP number *(if you know it)* — 1198013

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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11. I/We request the grant of a patent on the basis of this application.

Signature	Date
Murgitroyd & Company	16 November 1998

12. Name and daytime telephone number of person to contact in the United Kingdom — John Cooper — 0141 307 8400

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"Defect Correction in Electronic Imaging Systems"

The present invention relates to methods and apparatus for correcting defects in video data generated by electronic imaging systems. The invention is most particularly concerned with the correction of defects arising from defective pixel sites in electronic image sensors, but is also applicable to more general noise reduction in video data streams. The invention is equally applicable to monochrome and colour video data and may be useful in relation to still imaging systems as well as kinematic video systems.

The majority of electronic imaging devices are now implemented using semiconductor technologies. Examples include the CCD, which is implemented using a form of MOS manufacturing process, and, more recently, image sensors manufactured using standard CMOS semiconductor processes.

In all of these cases, the sensor normally comprises a 1- or 2-dimensional array of discrete pixels.

It is in the nature of the manufacturing processes employed in the production of such devices that

occasional defects occur at individual pixel sites. Such defects may variously cause the affected pixel to be unrepresentatively brighter or darker than the true image at that point (including the extreme cases of saturated white or black pixels).

Such defects affect some proportion of the population of individual imaging devices ("chips") on each manufactured wafer. Chips so affected must normally be rejected for use unless the defects can in some way be masked or corrected. It is economically attractive to mask or correct defective pixels enabling otherwise rejected chips to be passed as good product. This improves the apparent yield of good imaging chips per wafer and thereby lowers the cost per usable chip.

It is known in the art to calibrate imaging devices at the point of camera manufacture, so that the locations of defective pixels in the imaging array are identified and stored. In subsequent use of the device, pixel data from these locations is in some way masked or corrected in the live video data stream.

One simple and well known masking technique is to substitute for the defective datum a copy of the value of a neighbouring pixel. More sophisticated techniques are also possible and typically may produce an estimate of the correct value of the defective pixel data by applying an algorithm to the data obtained from the neighbouring pixels in one or two dimensions. Generally, the best correction filters use a mixture of linear and non-linear estimators and work on at least a 3 x 3 pixel neighbourhood centred on the defective pixel.

This prior technique of calibrating individual sensors

at the point of manufacture has two main disadvantages. Firstly, and most significantly, the process of calibrating the sensor to determine defect locations is an inconvenient and expensive manufacturing burden. Secondly, defects may sometimes be transient in nature, so that defects present and corrected for at the time of calibration may subsequently disappear, or, worse, new defects may occur subsequent to calibration. These latter defects will remain uncorrected in subsequent camera use and will show clearly as blemishes on the images output by the camera.

It is a first object of the present invention to provide methods and apparatus for the correction of defects in electronic imaging systems which obviate or mitigate the above mentioned disadvantages of prior art image defect correction schemes.

Whilst the invention may be implemented using known error correction algorithms for correcting the pixel values output by defective pixel sites, it is a further object of the invention to provide improved methods and apparatus for filtering video data signals, both for the purpose of correcting image defects originating from defective pixel sites and for more general noise reduction purposes.

The invention, in its various aspects, is defined in the Claims appended hereto. Other features and aspects of the invention and of the preferred embodiments thereof will be apparent from the following description.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram illustrating a first embodiment of the invention;

Fig. 2 is a block diagram illustrating a preferred embodiment of the invention;

Figs. 3(a) and 3(b) are illustrations representing pixel neighbourhood locations employed in correcting image defects;

Fig. 4 is a more detailed block diagram illustrating a particularly preferred implementation of the embodiment of Fig. 3; and

Fig. 5 is a graph illustrating the operation of a digital filter employed in the embodiment of Fig. 4.

Referring now to the drawings, Fig. 1 illustrates a first, most general embodiment of the invention.

An image sensor 10 of known type comprises an array of pixels. The sensor array 10 outputs an analogue data stream which is converted to digital form by analogue to digital conversion means 12. Assuming a two dimensional pixel array, the data stream comprises a series of pixel values output line by line from the sensor 10. The digital data stream would normally be encoded by encoding means 14 in a manner to suit the intended end use of the video data.

In accordance with the present invention, the live video data stream is filtered in real time by digital filter means 16 so as to correct or mask anomalous pixel values which are judged to arise from defective pixel sites in the sensor 10. Typically, the filter 16

judges a pixel value to be defective if it is significantly higher or lower than its neighbours in either one or two dimensions. The filter replaces the defective pixel value with a substitute value. The substitute value may be derived by any suitable algorithm, which may involve linear and/or non-linear processes which may operate on surrounding pixel data from a one- or two-dimensional neighbourhood surrounding the defective pixel value.

The filter 16 works permanently on the normal sensor output and does not require the use of any reference scene or predetermined calibration data. Rather, the filter depends on predetermined criteria for identifying defective pixel values in the live data stream and on predetermined rules for deriving substitute pixel values to replace the defective pixel values.

This "live" or "in-line" correction of defective pixels overcomes the manufacturing burden of prior art techniques and deals automatically with defects which arise after manufacture. It further provides a degree of noise filtering on noisy images, correcting excessively large single-pixel noise spikes.

Applying automatic correction in this way to an entire image can, in some circumstances, cause an undesirable deterioration in the overall image quality unless the correction filter is constrained in severity. This limits the effectiveness of the technique in its most basic form.

The Applicant has found that the most suitable class of pixel-correcting filter is one which uses the central pixel data itself as part of the data set used to

determine the correction to be applied. Typically, this means that the non-defective portions of the image (that is, the majority of each image) are unaffected by the presence of the correcting filter. The filter will, however, correct defects of large magnitude.

Unfortunately, many defects which it would be desirable to correct are not of large magnitude. Typical examples are pixels with a significant gain error, or pixels which are stuck at an intermediate image value. It has not been found to be possible to devise a single filter which is capable of correcting for these more subtle defects which does not also falsely correct many non-defective pixels in a manner which has an undesirable effect on the overall image, such as by producing a smearing effect.

Fig. 2 illustrates a preferred embodiment of the invention, in which the single filter 16 of Fig. 1 is replaced by first and second filter stages 18 and 22 and a defect memory or database 20. In accordance with this scheme, the first filter stage 18 performs two functions. Firstly, it applies a more subtle correction algorithm to the complete data stream, so as to correct defects of lower magnitude as noted above. Secondly, it identifies pixels exhibiting more extreme defects, and passes information regarding these pixels to the defect memory 20, which stores information regarding those pixels which are judged to be most severely defective. The defect memory 20 controls the operation of the second filter stage 22, which applies more severe correction selectively to those pixels identified in the defect memory 20. Typically, the number of pixels for which severe correction is required will be less than 1% of the total pixel count. The pixel locations stored in the defect memory 20 are

restricted to those that, historically, appear to be most severely in error as detected by the first filter stage 18.

That is, for each video frame (or for each still image captured by the sensor), all defects are monitored by the first filter stage 18 and those pixel locations exhibiting the largest apparent errors are added to the defect memory 20, if not already identified and stored.

In order to enable the contents of the defect memory 20 to remain dynamic over time, a management strategy is required so that locations representing transient noise defects or defects which disappear over time can be identified and removed from the defect memory 20. Besides preventing future correction of non-defective pixel values, this also creates memory space for new or previously undetected defects (the memory space 20 is necessarily limited and it is desirable that it be as small as possible consistent with the number of defects which are likely to be encountered in practice).

Typically, the defect memory 20 might store less than 1% of all possible pixel locations. Accordingly, no more than 1% of pixels will be subject to severe correction. This proportion is so low as to be unnoticeable to a human observer of the corrected video or still image.

A preferred embodiment of the scheme illustrated in Fig. 2 will now be described with reference to Figs. 4 and 5.

Referring firstly to Figs. 3(a) and 3(b), these illustrate examples of "pixel neighbourhoods" operated on by digital filters of the type employed in the

invention. In a two-dimensional pixel array, each pixel (neglecting the pixels at the edges of the array) is surrounded by eight immediately neighbouring pixels, forming a 3 x 3 array. The particular pixel operated on by a filter at any point in time is the central pixel p(c) of the 3 x 3 array. Fig. 3(a) illustrates the situation when the filter includes the central pixel value along with the values of the surrounding eight pixels in the dataset employed to determine a substitute value for p(c). Fig. 3(b) illustrates the situation when the filter excludes the central pixel value from the dataset employed to determine a substitute value for p(c). These two alternatives are both employed in the two stage filtering provided by the preferred embodiments of the present invention, as shall be described in greater detail below. It will be understood that the use of a 3 X 3 array for the filter dataset is merely an example, being particularly applicable to monochrome image sensors. Larger and/or differently oriented arrays may be appropriate in some circumstances, particularly for colour sensors, and the approach described in the present example can clearly be extended to other shapes or sizes of array.

Referring now to Fig. 4, there is shown a block diagram of a video data filtering system corresponding to blocks 18, 20 and 22 of Fig. 2. The input data stream consists of a series of input pixel values p(in) and the output datastream consists of a series of output pixel values p(out).

The input datastream is firstly sampled by a sampling network consisting of line memory buffers 30 and 32, each of which is capable of storing a complete line of video data, and individual pixel value memory buffers 34, 36, 38, 40, 42 and 44. The incoming video signal

is routed through the line buffers 30, 32 and into the pixel buffers 34 - 44 so that, over a number of clock cycles, nine pixel values for the central pixel p(c) and surrounding neighbours are accumulated to be operated on by the filter system. The line buffers 30, 32 suitably comprise random access memory, while the pixel buffers 34 - 44 may be D-type flip-flops.

The central pixel value p(c) is extracted on line 46 as shown, while the eight neighbouring values are applied to block 48. Block 48 sorts the values of the neighbouring pixels into rank order according to their amplitudes, and outputs the values in rank order, with the highest value output on the upper output line 48U and the lowest value on the lower output line 48L. In this example, the filter system only employs the highest, lowest and middle two ranking values out of the eight input values. However, variations on this example could utilise other combinations of the eight ranked values, as shall be discussed further below.

The ranked values of the neighbouring pixels are employed by both the first and second stage filter processes 18 and 22 of Fig. 2. In fact, the two filter stages share components and functions of the embodiment illustrated in Fig. 4, rather than being discrete systems as shown in Fig. 2. However, their essential functionality is separate and is in accordance with the schematic representation provided by Fig. 2.

The first stage filtering operates to apply relatively subtle correction to the entire data stream while at the same time identifying defect locations to which the second stage filtering is to be applied, as follows.

The highest and lowest ranked pixel values on lines 48U

and 48L and the central pixel value p(c) on line 46 are input to block 50, which operates as a "one from three" multiplexer. Block 50 compares p(c) with the highest and lowest ranked values. If the value of p(c) is greater than the highest ranked value then the highest ranked value is output from block 50, replacing p(c) in the data stream. If the value of p(c) is less than the lowest ranked value then the lowest ranked value is output from block 50, replacing p(c) in the data stream. If the value of p(c) is less than the highest ranked value and greater than the lowest ranked value, or is equal to either value, then the value of p(c) is output from block 50, so that p(c) is unaffected by the first stage filter.

This filtering scheme is illustrated in Fig. 5, in which the rank of the input pixel value is plotted against the rank of the pixel value which is output by the filter. The nine ranks of this example are numbered from -4 to +4, with zero being the rank of the median pixel value. The graph shown corresponds to the scheme described above. If p(c) is ranked +4 then it is replaced by the value of rank +3. If p(c) is ranked -4 it is replaced by the value of rank -3. Otherwise it is unaffected by the filter.

The filter could be modified to allow maximum values restricted to ranks 1 or 2, as indicated by the dot-and-dash lines, in which case different outputs from block 48 would be employed. The filter could also be made to be switchable between these different modes of operation if required. The horizontal axis of Fig. 5 corresponds to a "median filter", in which the median value is output regardless of the input value. The diagonal line through the origin indicated by the dashed lines corresponds to zero filtering, in which

the output is always equal to the input.

Since this filtering operation is applied to the entire data stream, it acts as a general noise reduction filter as well as correcting relatively subtle defects arising from defective pixel sites in the sensor array. As such it is potentially useful in applications other than that illustrated in Figs. 2 and 4. For example, it could be employed purely as a noise reduction filter in imaging systems using prior art calibration schemes to correct sensor defects. This filtering scheme will be referred to hereinafter as a "scythe filter" and its output value as the "scythe value".

The second stage filtering 22 of Fig. 2, in this example, is based on the median value of the pixels neighbouring the central pixel p(c). A conventional median filter applied to a 3 x 3 array would output a value corresponding to the median value of the nine pixels in the array. In the present case, it is preferred to neglect the value of the central pixel, since this has already been presumed to be erroneous when the second stage filtering is applied. Accordingly, a median value is calculated based on the values of the eight neighbouring pixels, excluding the central pixel p(c) as shown in Fig. 3(b). Since there is an even number of neighbouring pixels, the median value used is the mean value of the two middle ranking pixel values. The sorting of the neighbouring pixel values into rank order, described above, facilitates this. As seen in Fig. 5, the values of the two middle ranking values output from block 48 are summed and divided by two, to provide a pseudo-median value.

This filtering scheme will be referred to hereinafter as a "ring median filter" and its output as the "median

value".

In the example of Fig. 4, it can be seen that scythe (first stage) filtering and ring median (second stage filtering) both take place in parallel on the entire data stream. Both the scythe and median values are input to a final "one from two" multiplexer 52, the final output p(out) being determined by the contents of the defect memory 20 of Fig. 2. If the pixel location corresponding to the central pixel p(c) is stored in the defect memory 20, then multiplexer 52 will select the ring median value as the final output value. Otherwise, the final output value will be the scythe value. Since the pixel locations stored in the defect memory 20 comprise only a small proportion of the total number of pixels in the sensor array, scythe filtering will be applied to the majority of the data stream with ring median filtering being applied to the remainder.

In Fig. 4, the defect memory 20 of Fig. 2 is represented by memory block 54 and memory management block 56.

The pixel locations stored in the defect memory 20 are those which exhibit the most extreme differences from their neighbours. In the embodiment of Fig. 4, pixel locations are selected for inclusion in the defect memory on the basis of the magnitude of the difference between the value of p(c) and the scythe value output from block 50. The difference between the two values is determined at 58 and the absolute magnitude of this difference at 60. The decision as to whether a particular pixel location should be stored can be based on a wide variety of criteria, depending in part on the size of the defect memory and on the memory management strategy employed. In the present example, a simple

scheme is employed whereby the single worst defect (i.e. the greatest difference between the value of p(c) and the scythe value) in each video frame is stored in the defect memory. For each frame, the worst defect to date is stored in buffer memory 62. At the end of the frame, the value stored at 62 is passed to the memory block 54, together with its corresponding location in the sensor array. The data stored in the memory 54 is essentially a sorted list of pixel locations and associated defect magnitudes. Additional information could be stored if necessary.

It will be understood that the beginnings and endings of video frames and the locations of pixels corresponding to pixel values in the data stream can be derived by the use of clocks, counters and information included in the data stream, in a manner which will be familiar to those skilled in the art. Systems for performing these functions will not be described herein and are excluded from the drawings for the sake of clarity.

The memory management unit 56 controls the output multiplexer 52 so as to select the ring median value as the final output when the current pixel corresponds to a location stored in the memory block 54. Otherwise, the scythe value is selected.

As noted above, a strategy is required for managing the contents of the memory block 54. This is accomplished in the present example by means of a first-order auto-regression function (also known as "leaky integration"). That is, the magnitudes of the defects stored in the memory are continually updated by means of the auto-regression formula. Once the memory 54 is full, the locations with lowest defect magnitudes can

be replaced by newly detected defects of greater magnitude. The magnitudes of persistent defects will be refreshed by normal operation of the filtering system, whilst the stored magnitudes of transient defects will gradually attenuate until they are replaced.

In this example, the magnitudes of stored defects are updated by determining the difference between the current pixel value p(c) and the ring median value at 64, and the absolute magnitude of this difference at 66. The updated value is calculated using the auto-regression formula at 68, from the current stored value for the relevant pixel location and magnitude of the difference between p(c) and the ring median value, and the stored value is updated accordingly. The location of the current, lowest stored value is stored in memory buffer 70 so that this value (MIN) can be replaced by a new defect location and value (MAX, 62) once the memory 54 is full.

It can be seen that Fig. 2 represents a generalised version of the preferred embodiment, employing a stored list of defect locations to apply two stage filtering to an incoming data stream, with the first stage filtering also serving to determine which locations are stored and the second stage filtering being switched on and off on the basis of the stored list. As seen in Fig. 4, this functionality is implemented by applying both filtering functions in parallel and selecting which filter output to use on the basis of the stored list, with the first stage filter output also being employed in the selection of locations for storage and the second stage filter output also being employed in the management of the stored list.

Other variations of the described embodiments can be envisaged, using different filtering functions, different data sampling schemes and different memory management strategies. Such variations and other modifications and improvements may be incorporated without departing from the scope of the invention as defined in the Claims appended hereto.

Claims

1. A method of processing a video data stream comprising a series of pixel values corresponding to pixel sites in an electronic imaging device so as to correct defective pixel values, comprising filtering the video data stream in real time so as to correct or modify defective pixel values.

2. A method as claimed in Claim 1, wherein the filtering of each pixel value is based on the values of a plurality of neighbouring pixel values.

3. A method as claimed in Claim 2, wherein the filtering of each pixel value uses the value of the current pixel as part of a dataset including the values of said neighbouring pixels in determining whether and/or how to correct or modify the current pixel value.

4. A method as claimed in any preceding Claim, further including the step of identifying those pixel values which are most severely defective, storing the locations of said most severely defective pixels in a defect store, applying a first filtering algorithm to those pixels whose locations are not stored and applying a second filtering algorithm to those pixels whose locations have been stored.

5. A method as claimed in Claim 4, wherein the filtering of each pixel value is based on the values of a plurality of neighbouring pixel values and said first filtering algorithm uses the value of the current pixel as part of a dataset including the values of said neighbouring pixels.

6. A method as claimed in Claim 5, wherein said first filtering algorithm comprises sorting the values of the current pixel and of said neighbouring pixels into rank order and modifying the current pixel value on the basis of its place in said rank order.

7. A method as claimed in Claim 6, wherein the value of the current pixel is modified if its rank is greater than or less than predetermined maximum and minimum rank values.

8. A method as claimed in Claim 7, wherein:

the current pixel value is replaced by the value of the pixel having said predetermined maximum rank value, if the current pixel value has a rank greater than said predetermined maximum rank value;

the current pixel value is replaced by the value of the pixel having said predetermined minimum rank value, if the current pixel value has a rank less than said predetermined minimum rank value; and

the current pixel value is left unchanged if the current pixel value has a rank less than said predetermined maximum rank value and greater than said predetermined minimum rank value.

9. A method as claimed in Claim 8, wherein said predetermined maximum rank value is the highest ranking of said neighbouring pixels and said predetermined minimum rank value is the lowest ranking of said neighbouring pixels.

10. A method as claimed in any one of Claims 4 to 9, wherein pixel locations to be stored in said defect store are selected on the basis of the output of said first filtering algorithm.

11. A method as claimed in Claim 10, wherein the decision to store a pixel location is based on the magnitude of the difference between the current pixel value and the pixel value output by said first filtering algorithm.

12. A method as claimed in Claim 11, wherein, for each frame of video data, the location of at least that pixel value having the greatest difference in magnitude from the output of the first filtering algorithm is stored in said defect store.

13. A method as claimed in any one of Claims 4 to 12, wherein the filtering of each pixel value is based on the values of a plurality of neighbouring pixel values and said second filtering algorithm excludes the value of the current pixel from a dataset including the values of said neighbouring pixels.

14. A method as claimed in Claim 13, wherein said second filtering algorithm replaces the value of the current pixel with the median value of said neighbouring pixels.

15. A method as claimed in any one of Claims 4 to 14, wherein the information stored in said defect store includes the location of each pixel selected for storage and information indicating the severity of the defect.

16. A method as claimed in any one of Claims 4 to 15, wherein the contents of the defect store are updated in accordance with a predetermined memory management algorithm.

17. A method as claimed in Claim 16, wherein said

defect store includes the location of each pixel selected for storage and information indicating the severity of the defect, and wherein said information regarding the severity of the defect is updated on the basis of an auto-regression function applied to the current value of each stored pixel value, the current output from the second filtering algorithm and the current stored value.

18. A method as claimed in any one of Claims 4 to 17, wherein said first and second filtering algorithms are applied to the video data stream in parallel and the final output pixel value is selected from the outputs of the first and second filtering algorithm depending on whether the corresponding pixel location is present in the defect store.

19. Apparatus for processing a video data stream comprising electronic filter means adapted to implement the method as defined in any one of Claims 1 to 19.

20. Apparatus as claimed in Claim 19, comprising means for sampling a video data stream in order to obtain a data set comprising a current pixel value and a plurality of neighbouring pixel values.

21. Apparatus as claimed in Claim 20, further including means for sorting said neighbouring pixel values into rank order.

22. Apparatus as claimed in Claim 21, further including means for comparing the current pixel value with neighbouring pixel values of selected ranks and for generating a first filter output on the basis of said comparison.

23. Apparatus as claimed in Claim 22, further including means for determining the median value of said neighbouring pixels and generating a second filter output equal to said median value.

24. Apparatus as claimed in Claim 23, further including a defect store for storing pixel locations selected on the basis of said first filter output.

25. Apparatus as claimed in Claim 23, further including output means for generating a final output pixel value selected from said first and second filter outputs on the basis of the contents of said defect store.

26. An electronic imaging system including an image sensor array having an output connected to apparatus as claimed in any one of Claims 19 to 25.

27. A method of filtering a video data stream comprising a series of pixel values corresponding to pixel sites in an electronic imaging device, wherein the filtering of each pixel value is based on the values of a plurality of neighbouring pixel values using the value of the current pixel as part of a dataset including the values of said neighbouring pixels, and wherein said filtering comprises sorting the values of the current pixel and of said neighbouring pixels into rank order and modifying the current pixel value on the basis of its place in said rank order.

28. A method as claimed in Claim 27, wherein the value of the current pixel is modified if its rank is greater than or less than predetermined maximum and minimum rank values.

29. A method as claimed in Claim 28, wherein:

the current pixel value is replaced by the value of the pixel having said predetermined maximum rank value, if the current pixel value has a rank greater than said predetermined maximum rank value;

the current pixel value is replaced by the value of the pixel having said predetermined minimum rank value, if the current pixel value has a rank less than said predetermined minimum rank value; and

the current pixel value is left unchanged if the current pixel value has a rank less than said predetermined maximum rank value and greater than said predetermined minimum rank value.

30. A method as claimed in Claim 29, wherein said predetermined maximum rank value is the highest ranking of said neighbouring pixels and said predetermined minimum rank value is the lowest ranking of said neighbouring pixels.

31. Apparatus for processing a video data stream comprising electronic filter means adapted to implement the method as defined in any one of Claims 27 to 30.

32. An electronic imaging system including an image sensor array having an output connected to apparatus as claimed in Claim 31.

FIG. 1

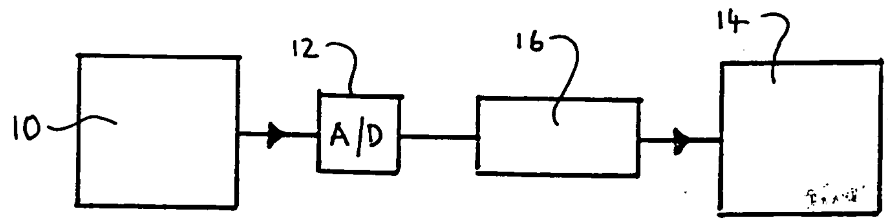
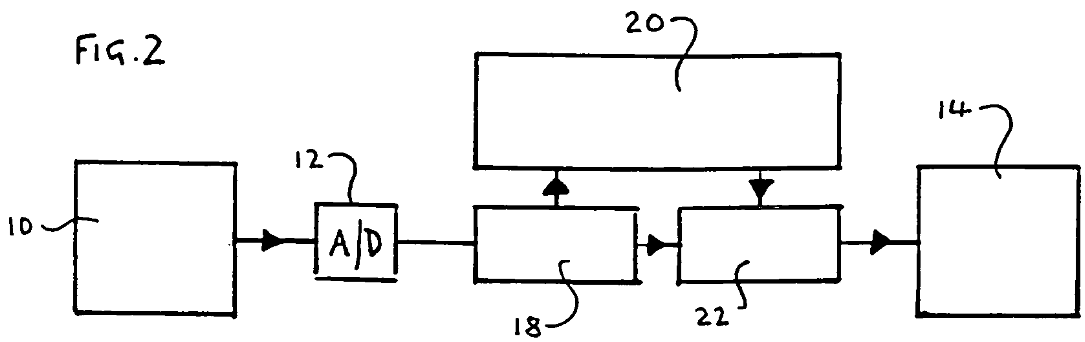


FIG. 2



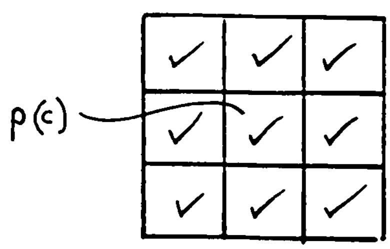


FIG. 3(a)

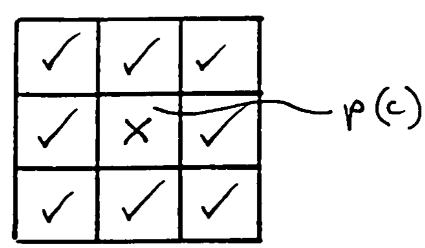
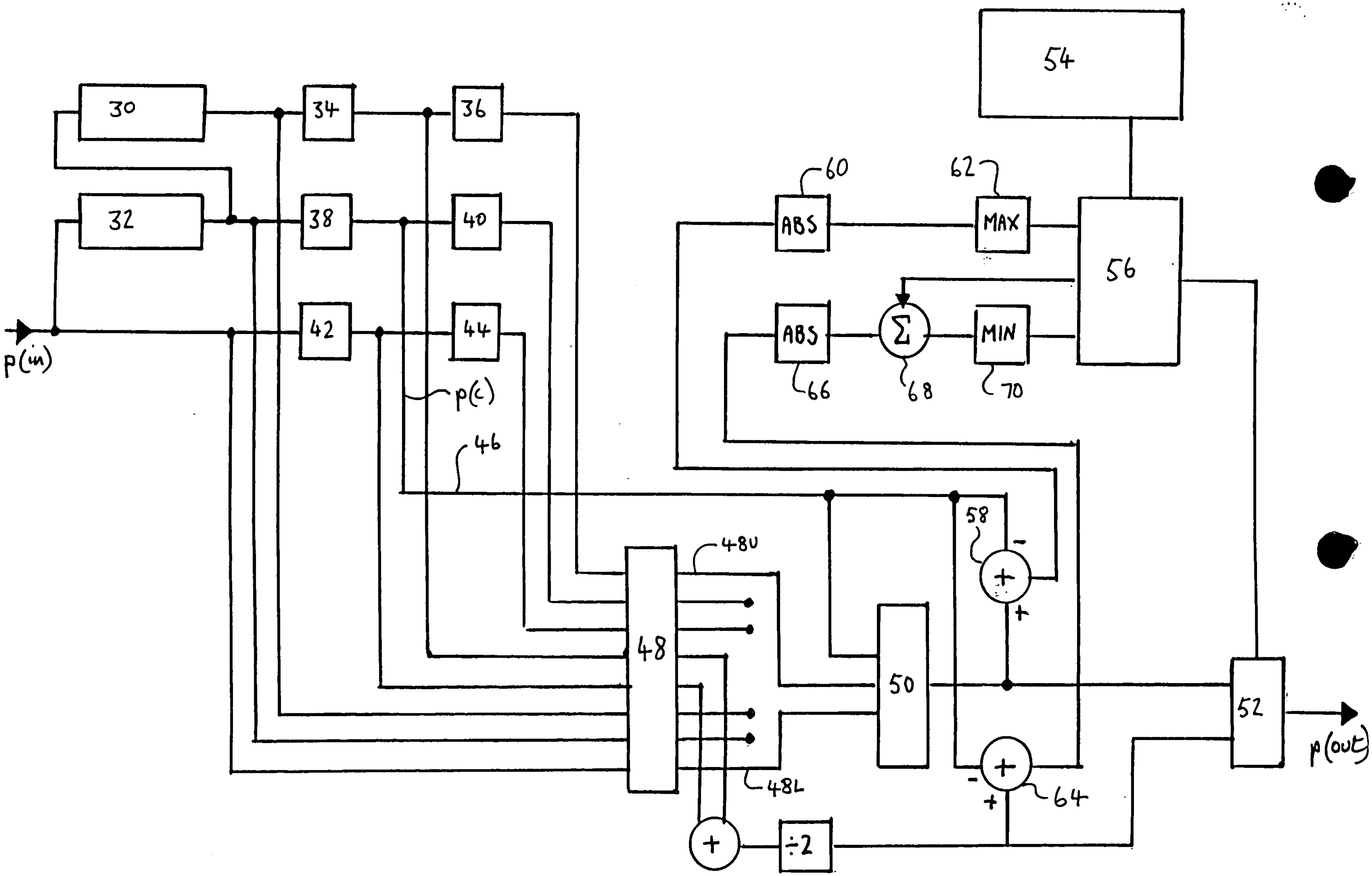


FIG. 3(b)

Fig. 4


30
32
34
36
38
40
42
44
p(in)
p(c)
46
48
48U
48L
50
52
p(out)
54
56
58
60
ABS
62
MAX
66
ABS
68
Σ
70
MIN
64
÷2

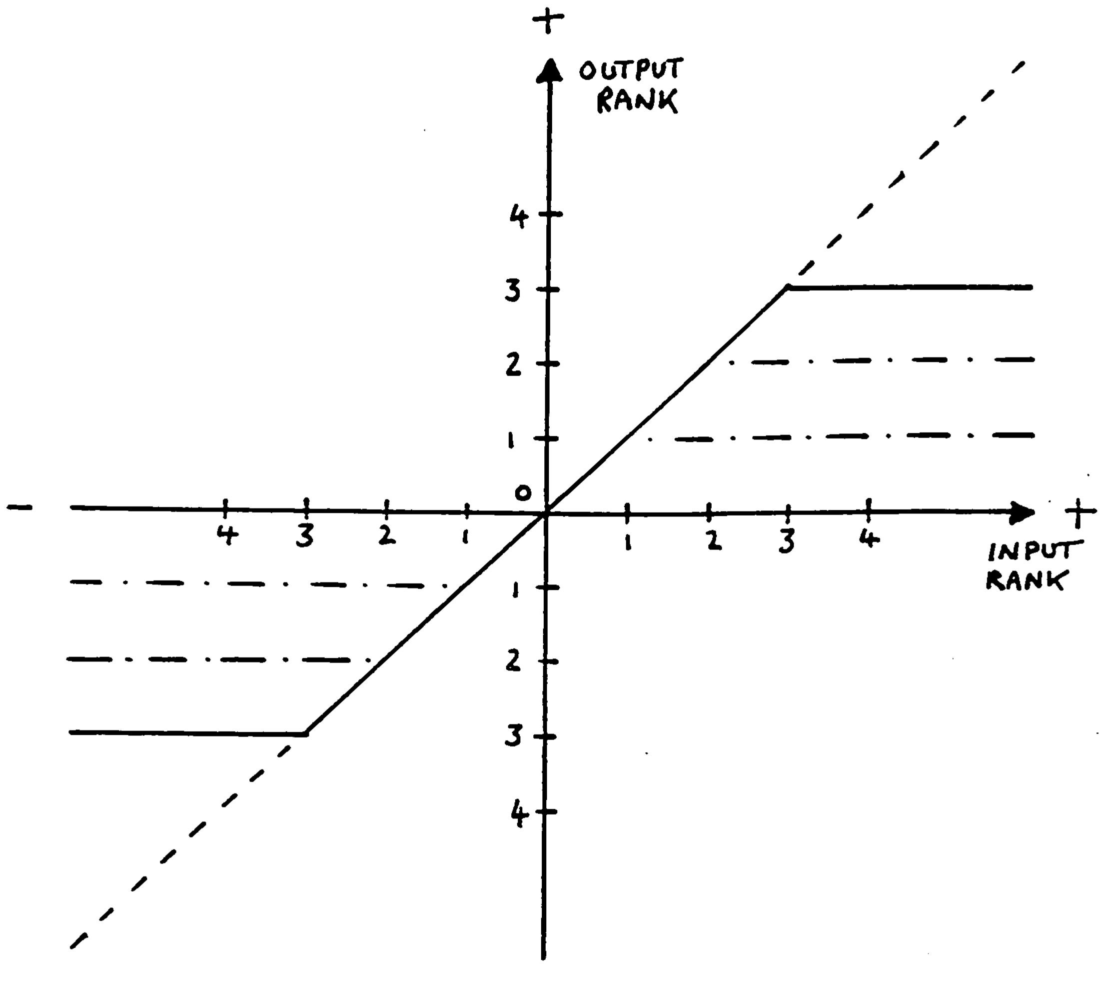


FIG. 5